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PLANE TABLE

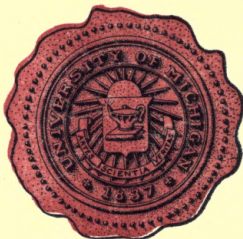
BY
JOSEPH E. DAVIS

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PLANE TABLE

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PLANE TABLE.

1. The Plane Table is a drawing board in connection with suitable devices for setting, and keeping it level. The alidade is a straight edge, called the rule and a line of sight. The line of sight is sometimes the edge of the rule, sometimes the line of a pair of compass sights set in the line of the edge of the rule, or it may be the line of sight of a telescope so mounted upon the rule that this line of sight revolves in a plane at right angles to the lower face of the rule. When a telescope is used, the plane of revolution of its line of sight is set parallel to the edge of the rule, or to contain the edge of the rule.

2. In the ordinary use of the Plane Table, a piece of paper is fastened on the board and the lines surveyed, and points that are determined, are platted at once upon the paper. A good quality of drawing paper is commonly used. This paper may be fastened on the board in a variety of ways. If it is to remain there long, and the board is well shrunk, it may be best to shrink it on and stick the edges fast with mucilage. It may also be tacked down with very small curtain tacks. Thumb tacks are used. Clamps are used, and rollers beneath the board are used to some extent. If the paper is larger than the board fasten the edges beneath the board. If the paper is so large as to be shifted from time to time to receive the extended drawing, it may be rolled and fastened beneath the board by thumb tacks or suit-

able clamps. In such a case the part of the paper on the top of the board should be tacked fast to prevent any shifting. When the paper is rolled under the board, the roll, or rolls, and the part of the paper where it passes over the edge of the board should be protected by a covering of stout paper. It is difficult to keep the paper clean. When the scale of the map is small, so that but a small place on the paper needs to be exposed at once, a newspaper may be lightly fastened over the paper on the board and torn away in small pieces to uncover the spots needed for use at any time. After a place is finished and no longer needed, it may be covered again with newspaper, or the newspaper covering may be changed at times, and the openings in it made to fit the work. In some kinds of work an extra sheet of paper may be useful for laying down lines upon, or for solving certain problems, connected with the work, which ought not to go upon the map or plat.

3. Center of the Sheet. The plane table should be set up over an instrument point in the same manner a transit is with a plumb bob from its center standing over the mark. The observations are then taken from the center of the sheet. The center of the sheet is that point on the paper which does not move when the board is turned about its spindle axis. This point may be found on each sheet, or a hole in the board made to mark it. To find the center of the sheet revolve the board on its axis and mark four fine marks on the board near its corners by a pencil or needle held by a fixed support. Find the center of the circle of which the four marks are a part of the circumference. To do this the

board may be taken off of its spindle and placed beside another board and so longer ranges be obtained in drawing the lines to the center. Draw all four lines. They should intersect at the same point. If they do not, try again. Having found this center on the board itself, a piece of brass may be set in the board with a hole in it to permanently mark the center. When a paper is fastened on the board, a few trials with a needle will prick a hole in the paper corresponding to the hole in the brass plate. The hole in the brass plate may be of the size to receive a common brass pin, which being set firmly in the hole may be a very useful aid in placing the alidade, when sighting. The center of the sheet should be found for use on every sheet or every time the sheet is shifted. The hole in the brass plate should be tested for position occasionally, to see that it stays in its place. If, for any reason, the connections of the board to the spindle are separated from the board, this test should be made when they are restored.

4. Articles for use with the Plane Table.

1. Two good triangles, 30° , 60° , 90° , from 9 to 12 inches, according to the size of the board, and the scale of the map. These may be of metal, rubber, celluloid, or wood, but should have straight edges. A place to keep them in may be made under the board.
2. Three legged dividers, with the third leg running through a tubular clamp, so the third leg may be varied in length, or removed.
3. Lead pencils, of the grade of No. 4 or 5 red hexagon, Faber.

4. Erasers—typewriter, velvet rubber, and sponge rubber.
5. Scale of equal parts for laying off distances.
6. Thumb tacks.
7. Curtain tacks—No. 1.
8. A little of Higgins' Drawing Board Mucilage.
9. Rubber cloth. A piece to cover the board and contents and fasten beneath it for protection from rain and dirt. Some may prefer two pieces, or one piece and a bag, the second piece or the bag being for the alidade.
10. A haversack, or better, a skeleton coat to carry the various tools and articles in. Even an article on the principle of a mechanic's apron with pockets on its front, is good. The skeleton coat is best.
11. For some work, a compass needle in a box. The box has a square or rectangular base with the edges beveled like a rule and parallel and perpendicular to the zero line of the compass ring. The compass needle is sometimes mounted on the rule of the alidade but the separate compass is better.
12. Adjusting pins, common pins, needle pricker and reading glass.

5. Setting up the Plane Table. Take the table and tools to an instrument point where it is desired that the table shall be set up. Lay the alidade and other tools in a safe place. Tie on the plumb bob. Set the table with its tripod, centrally over the mark of the instrument point. Spread the tripod legs so that when the table is finally set it will come at the elevation of the bend at

the middle of the body of the person who is to use it. Crowd the legs into the ground till the table will stand firm, and the plumb bob center the mark. The table is usually set too high. The arms are rested on the board, or the clothes rub against it, thus stirring it from its proper position. By setting it down to the bend in the body, one can lean over it more conveniently to look through the telescope or compass sights. Having attended to the placing of the table, stand the alidade centrally on the board. Turn the board, or the alidade, till the bubble tubes are parallel to the leveling screws. By operating the leveling screws make the bubble tubes both read level. Place the alidade centrally on the board in a new position. Level again, if needed. Proceed in this way till the table is as perfectly leveled as it can be.

After a little experience one may leave the board off while setting up the tripod.

See that the spindle clamp and slow motion screw are working well, that the leveling screws are all bearing somewhat firmer than for a transit, and that the tripod head (in some instruments) is screwed down tight to the tripod cap. Leave the spindle unclamped.

The center of the sheet being known, stick up a common pin there. Everything being found, or made, secure, and the board standing steady, and level, the plane table is ready for work.

6. The line of sight is set upon a point very much as in the case of a needle compass, or transit, with the difference that sometimes the alidade is moved on the paper by the hands in order to do it,

and sometimes the whole instrument is moved about its spindle axis and the line of sight set by the spindle clamp and slow motion screw, while the alidade stands still on the paper.

Points are located and line given by sighting with the telescope, the same as with a transit, or with the compass sights, the same as with a compass.

7. First work at first station of a survey.
Set up the table at the station. Choose a point on the paper to represent the station where the table stands, so that the rest of the survey will come good on the paper. Prick down the point and mark it for that station. Choose the direction on the paper in which the first line of the survey is to lie, when platted. Turn the board around so the assumed direction of the first line on the paper is, by estimation, parallel to the line itself on the ground, and the same end foremost. Clamp the spindle. Place the working edge of the rule of the alidade to the pin at the center of the sheet. With the hands, keep the rule to the pin, and bring the line of sight to look to another station of the first line of survey. By more delicate handling set the line of sight upon the mark at the distant station. Place one side of a triangle against the edge of the rule. Place the other triangle to the first, and slide the first over the paper till the edge that was against the rule comes to the mark on the paper for the first station. Draw a line through the mark parallel to and in the direction of the line on the ground. Slide the first triangle back to the rule and see if it still fits. If not review the work, and correct the errors. Make the line drawn of the measured, or estimated, length

of the line itself, to the scale of the plat, and mark, at its end, the second station of the survey.

8. General directions. Follow the edge of the rule, or triangle, carefully with the pencil held at the same inclination to the board for the whole length of the line. Keep the pencil sharp. Draw no more of a line than is needed. Avoid erasures, as much as possible. Be very particular when prolonging a line on the paper. Keep the edges of the triangles straight. Then they may be used to prolong a line by setting one of them to the line and the other to it from the opposite side of the line, when they may be slid past each other, alternately, in the direction the line is to go to the place the prolongation is to reach. This operation may be repeated and the position of the prolongation tested. If the edges of the triangles are distrusted apply them to the edge of the metal rule of the alidade, and try to look through between the parts in contact against a strong light. If the triangles are not true, they may be worked down with emory or sand paper, or a file, to fit the edge of the rule. They may also be ground down on a grindstone.

9. Always place the alidade with the rule on the same hand of the observer (either right or left, as is most convenient) on all lines of the same survey, when looking along them in either direction. Do not change hands with the rule when looking back over a line. Keep the rule in the same hand and bring it to the other side of the line. A right-handed person will naturally take the alidade in the left hand and always bring the rule to the left side of any line. A left-handed person would reverse this.

This would be the way to place the rule whether looking forward, or backward, along the line. This means that a telescope on an alidade would not be reversed on its axis but remain the same side up.

10. The two edges of the rule should both be beveled, be straight and parallel, so that either can be used to work from.

11. When carrying the table about, see that the board is securely fastened to the tripod head so it cannot fall off, and release the spindle clamp. The plane table is a clumsy instrument to handle. It must be carried with the more care and set down gently. Otherwise, the connections with the spindle or tripod head in many instruments can be easily injured so as to make the table useless. The broad connections below the board are much the best. Carry the alidade, and handle it by a grasp upon some part where a secure hold can be obtained, that will give good control of it. Alidades are usually so heavy that they should be made with a good hand hold. There are so many things to carry, some of which are awkward to handle, that it is best to consider carefully, such features

12. Preparations at a second station of a survey. These are to place the board in position for making observations at a station by means of a line platted on the paper which runs to that station. It is orienting the board by means of a platted line.

Set up the table at the station. Take out the pin at the center of the sheet. Place the edge of a triangle to the platted line. Slide the triangle by means of the other as if to draw a line at the center of the sheet, nearly covering the center of the

sheet. Hold the first triangle down steady with the fingers near the edge on the center of the sheet. With the other hand, bring the edge of the rule of the alidade up to the edge of the triangle at the center of the sheet. With a sliding movement of the alidade fit the edge of the rule to the triangle. Be careful not to shift the triangle, as it is easily moved by the heavier alidade. After setting the rule see if it stands parallel to the line it was set by.

If the spindle happens to be clamped, release it. Turn the board to direct the line of sight to the distant station on the line used in placing the alidade at the center of the sheet. Clamp the spindle. By the spindle slow motion screw set the line of sight on the mark at the distant station.

In placing the triangle to the line in the first place, and the alidade at the center of the sheet, have regard to the relative position of things on the table and on the ground, so that when the line of sight is finally set on the mark at the distant station, the line joining the plats of the stations on the board shall be parallel to the corresponding line on the ground and lie the same end foremost.

The board, or table, now stands parallel to its former position. It is oriented, and ready for work.

13. Measuring a vertical angle. Set up the table. Place the alidade central on the table, with the edge of the rule at the center of the sheet and the line of sight on a mark at the station on the line from which the vertical angle is to be measured. Set the horizontal cross wire on the mark that shows one side of the angle to be read, by means of the telescope axis clamp and slow motion screw. Read the

vertical circle. Record the reading. Release the telescope axis. By the means used before set the horizontal cross wire on the mark on the other side of the angle. Read the vertical circle. Record the reading. Release the telescope axis. By the same means set the horizontal cross wire again upon the first mark. Read the vertical circle. Record the reading. See if the first and last readings agree sufficiently well. If not, review the work and correct the errors. The difference of the readings will show the angle.

14. If the vertical angle is an angle of elevation or depression, set the horizontal cross wire on the mark as first above directed. Read the vertical circle. Record the reading. Release the telescope axis. By its clamp and slow motion screw set the telescope so its level will read level. Read the vertical circle. Record the reading. Reverse the alidade on the board and bring it up to the line with the rule on the opposite side of the center of the sheet. Set the telescope level to read level, if it needs it, by means of its slow motion screw. Read the vertical circle. Record the reading. Release the telescope axis. Set the horizontal cross wire on the mark again by means of the clamp and slow motion screw to the telescope axis. Read the vertical circle. Record the reading. See if the two middle readings (taken when the telescope was level) agree well. If they are very different, the board is not flat, or it is unsteady. It may be set firmer, but if it is uneven, the angle value will be poor. Having found the readings to be as good as practicable, find the angle by the first pair of readings, and also by the second pair.

Take the half sum of the two values for the correct one.

15. To measure the angle of elevation or depression of a line, measure the height of the telescope axis from the ground and sight to a mark at the same height from the ground at the other end of the line. If the line is not on the ground, measure the distance of the telescope axis from it in a similar manner, and sight to a mark at a corresponding distance from the line at another place on it. Measure the angle of elevation or depression of the line from the transit axis of the telescope to the corresponding mark at the station by the method described.

16. Rem. The work that can be done with the plane table depends directly upon the methods of ascertaining the position of a point with respect to other known points. These methods come first.

The expression "set the alidade" upon a line or mark means that the edge of the rule is to be placed at the center of the sheet and the line of sight set upon that line, or mark.

Capital letters denote points on the ground, and the small letters the plats of the same points on the sheet.

The work of the plane table can be done with a transit and drawing board, by platting the work as it goes on.

17. Determining a point by direct measurement. Orient the table at a known station. Set the alidade upon the line to the required point. Plat a line from a plat of the instrument station, parallel to the edge of the rule and running towards the re-

quired point. Measure the distance from the instrument station to the required point, by chain, steel tapes, or stadia. If the stadia is used, the telescope axis should stand at the center of the sheet. Lay off this distance, to the proper scale, from the station on the plat along the line drawn. Prick down the point thus reached, and mark it for the required point.

18. Determining a point by intersections.

Fig. 1. Let A and B be determined and platted at a and b . Set up the table at A and orient it by $a b$.

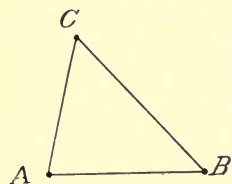


Fig 1

Set the alidade on a line to C. Draw from a , towards C, a line parallel to the edge of the rule, and continue it to the estimated position of c on the sheet. Set the alidade again upon A B. See if the edge of the rule is parallel to $a b$. If not, review the work and correct the errors. Take up the plane table. Set it up at B. Orient it by $b a$. Set the alidade on B C, a line to C. Draw from b , towards C, a line parallel to the edge of the rule till it intersects the line from a , parallel to A C. Set the alidade again upon A B. See if the edge of the rule is parallel to $b a$. If not, review the work and correct the errors. Prick down the intersection of the two lines drawn from a and b and mark this point c .

But a short piece of $a c$, or $b c$, or of both, may be needed, near c . Any number of points may be determined from a base A B. $a c$ and $b c$ should intersect as nearly as may be at right angles. If $a c$

and b c intersect at a small angle, the result cannot be trusted. Other lines to c from d , e , or f , other known points, will help to fix its position. A number of lines to c will not all intersect at the same point on the paper. The proper location of the point on paper is theoretically a question of mathematical adjustment, but there are usually some circumstances connected with the work which will enable the selection to be made properly.

19. Determining points by resection. This is in reality a method by intersections. The difference between this and the last case is, that one of the two lines necessary to determine the point is drawn on the paper, while the table is set up at the point whose position is sought. In the previous case objects may be located, or determined, without going to them. In the case of resection the table is set up at the station, or object, whose position is sought. This is an advantage in carrying out work, as the table may be advanced to a station before it is on the map, if there is a line on the paper that runs to it from some known station that is in sight from it. By referring to Fig. 1 the principle of this method may be stated. Let A and B be known and platted, at a and b . Set up the table at A and orient it by a b . Set the alidade on a line to C. Draw from a , towards C, a line parallel to the edge of the rule, and continue it to where c is thought to be on the paper, or beyond. Set the alidade again upon A B. See if the edge of the rule is parallel to a b . If not, review the work, and correct the errors. Take up the plane table. Set it up at C. Orient it by the indefinite line from a , towards c . Set the alidade on C B. Draw

from *b* (towards *C* were the table at *B*), a line intersecting the indefinite line from *a*, and parallel to the edge of the rule. Set the alidade again upon *C*. See if the edge of the rule is parallel to the indefinite line from *a* towards *c*. If not, review the work, and correct the errors. In a similar manner lines may be drawn on the map, or plat, from any number of stations in sight from *C*, whose positions have been platted. Several lines thus drawn, running to *c*, will help fix its position with much greater precision.

20. Rem. A single intersection is not sufficient to fix a station on the plat. A direction line and a measured distance are not alone sufficient. When a point is to be determined by intersection, there should be a number of lines observed that run to it. When a point is to be determined by measurements, there should be two or more. A combination of intersecting lines and measurements may be used. The position of any station on the plat should not be used to determine the position of any other station, or object, unless its own position has been well checked. Every available check upon the position of a station should be used. Neglect no chance to tie up a station. A check which shows an error in the position of the station tested, may really reveal an error in the position of the station from which the test comes. A check works at both ends, and tests the position of both stations concerned. What constitutes a good determination of a point? This can be ascertained only by experience upon any particular work, and with the instruments in use. The stadia may be used with the best plane table to get distances and heights no much work. For general topographical surveys

the stadia will probably give good results. When filling in final details to a large scale, it may be found unsuitable, especially as to elevations. Any general statement relating to such matters must be materially modified by the person doing the work and the circumstances of the case. These facts render such statements of little value.

21. In orienting the table use more than a single line, where practicable, no matter how well that line may have been determined. That is, orient by a line, and test the orientation by sights to other stations, if possible. This serves to further check the plat.

22. The advantage of resection is, that after one or more lines to the new station have been platted, it is possible to set up the table at that station, and by observing to other stations get a number of lines running to the new station with a single setting of the table, when by intersections, each of the stations observed would have to be occupied. This is often a very great advantage. With some patience, it is conceivable that the table might be oriented at a new station by persistent trial in taking pointings on other stations, at the same time the new station was determined. There are better ways of doing this, given below.

23. Determining a point by the "Three Point Problem" and orienting the table. Fig. 2. Let the three points, A, B, and C, be well determined upon the plat. Let the position of D, from which A, B, and C, can be seen, be required, without going to them.

Fasten an extra piece of paper over the middle of the board. Find the center of the sheet on this paper. Call the center of the sheet on this paper m .

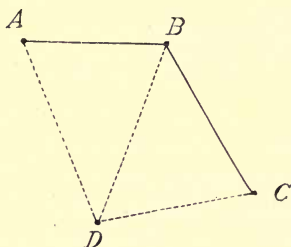


Fig 2

Set up the table at D. Clamp the table so the extra piece of paper will receive the lines DA , DB , and DC , when platted from the center of the sheet. Set the alidade on DA and draw a line, by the edge of the rule, from m towards A . Set the

alidade on DB and DC , in succession, and draw lines from m towards B and C , respectively. Notice the position of D with respect to ABC , that is, see if D lies on the convex or concave side of the broken line ABC . Fit the three legged dividers to the platted positions, on the plane table sheet, of the points A , B , C . Make the fit carefully. Apply the points of the dividers to the lines from m towards A , B , and C , each point of the dividers upon the line running towards the point it was fitted to the plat of. By careful adjustment, make the points of the dividers fit the three lines. Prick down the points on the lines where the dividers fit. The center of the sheet, m , on the extra piece of paper, is in the same relative position with respect to the three points, on the three lines, that were pricked down with the points of the three legged dividers, that D is with respect to A , B , and C , on the ground, and may be transferred to the plane table sheet with the three legged dividers,

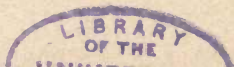
thus obtaining the correct plat of all four points.

Orient the table by means of a line from the plat of D, on the plane table sheet, to the plat of either A, B, or C, and test its position by lines to the other points. Use the longest line to orient by.

When the plats of A, B, and C cannot be embraced by the three legged dividers, use the same equal parts of the lines from the plat of B to the plats of A and C, and take up the plat of B, and the two auxiliary points with the dividers. Fit the dividers to the three lines from *m* as before. The point *m* will form the fourth angle of a quadrilateral whose sides bear the same ratio to the sides of the one required on the plat, that the parts first used to do the whole lines used on the plat. Fix a third auxiliary point on the plat with respect to the plat of B and the two first auxiliary points with the dividers. Draw auxiliary lines from this third auxiliary point to the others and to the plat of B. Extend the line to the plat of B beyond the third auxiliary point. Draw lines from the plats of A and C, respectively parallel to the near sides of the quadrilateral of auxiliary lines and produce them to intersect. They should intersect on the line from the plat of B. If they do not, review the work, and correct the errors. This intersection is the plat of D.

24. Determining a point by the "Two Point Problem," and orienting the table. Fig.

3. Let two points, A and B, be well determined on the plat. Let the position of C, from which A and B can be seen, be required, without going to them. This is possible when a fourth point D can be occupied which is in sight from C, and from



which A, B, and C, can be seen. D may be made use of in continuing the survey, or not. Assume a station, D.

Fasten an extra piece of paper over the center of the board. Find the center of the sheet on this paper, and call it *m*. Set up the table at D. Clamp the table so the extra paper will receive a plat of the quadrilateral A B C D. Set the alidade on D C, and draw a line, by the edge of the rule, from *m* towards C. Set the alidade on D A and D B, in

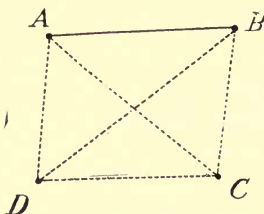


Fig. 3

succession, and draw lines from *m* towards A and B respectively. Remove the table to C, and set it up there. Orient the table by the line from *m* towards C. Assume any convenient length from *m* on this line to represent the length of D C, and prick down, on the extra paper, a temporary plat of C. Set the alidade on C A and C B, in succession, and complete, upon the assumed length for D C, a temporary plat of A B C D. By this means obtain a temporary plat of A B upon the extra piece of paper. The angle between the plat of A B on the plane table sheet and the temporary plat of A B on the extra sheet is the amount the board is to be turned to correctly orient it with respect to A B on the ground and the plat of A B on the plane table sheet. Set the alidade at *m* parallel to the temporary plat of A B upon the extra sheet. Find or fix a mark in range of the line of sight. Set the alidade at *m* parallel to the correct plat

of A B on the plane table sheet. Release the spindle clamp. Set the line of sight on the mark by means of the spindle clamp and slow motion screw. The table is oriented correctly with respect to A B. Resect upon A and B to determine C.

After orienting the table its position may be tested. Set the alidade on *m* and parallel to the temporary plat of either C D or C B on the extra sheet. Release the spindle clamp. Set the line of sight on D, or B, by means of the spindle clamp and slow motion screw. Set the alidade on *m* and parallel to the temporary plat of A B on the extra sheet. The line of sight should strike the mark formerly used.

Particular notice must be taken to observe which side of A B, the station C is on the ground and to conform the temporary plat to the position of the stations on the ground so as to prevent reversing the table when finally orienting it, or of using the supplement of the proper angle when making that orientation.

If D is to be used in continuing the survey ; after resecting upon A and B to get C, set the alidade on C D and draw a line from the plat of C to get the plat of D. Move the table. Set it up at D. Orient it by the line from the plat of C towards D. Resect on A and B to get D. It should fall on the line from the plat of C.

The quadrilateral on the plane table sheet, or the triangle A B C, in case D is not platted on the plane table sheet, may be compared with the temporary plat upon the extra sheet. The angles should be equal, and the sides proportional.

C D may lie in any relation to A B—cross it if necessary.

25. When it is possible to set the table in line with A B, by trial, as at D, Fig. 4, orient it by *a b* at once. Set the alidade on D C and draw a line towards C, anywhere on the sheet. Move the table to C. Set it up. Orient it by the last named line. Resect on A and B to get C. Set the alidade on C D. Draw a line from *c* parallel to C D to intersect *a b* produced for *d*.

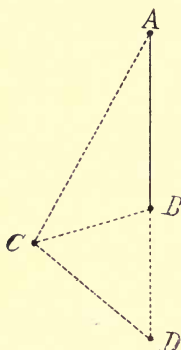


Fig 4

26. Elevations. Differences in elevation as obtained with the plane table may be good enough for some topographical surveys. They may be obtained in several ways.

Except those of the rudest character, they require a telescope on the alidade, a vertical circle or arc, a level on the telescope, or both. The telescope level should be a striding level; of the Berger pattern, standing on collars turned on the body tube of the telescope. These levels are readily attached and detached, and cannot drop off. The telescope may be furnished with stadia wires and the stadia used to get heights and distances both. The distances may be used to check those obtained by platting on the sheet.

27. If a telescope is used, the height of the transit axis from the under side of the rule should be measured and kept in mind in taking heights. This distance added to the height of the table above the ground, at any station will give the height of the line of sight of the telescope above the ground when hor-

izontal, or the height of the transit axis from the ground.

28. If compass sights are used and rough levels are wanted let a line be drawn parallel to the under side of the rule near the top of the sights on one side for depressions, and near the bottom of the sights on the other side, for elevations. On the rear sight place a peep sight on each of these lines. On the front sight mark graduations, or a scale of feet per hundred, like the tangent scales on compass sights, for elevations on one side and depressions on the other. Find the height of each level line from the under side of the rule to be added to the height of the table from the ground, to get the height of the level line of sight from the ground.

29. Taking differences of elevation. With the plane table set up at a station, to get the difference in elevation from the ground under it to the ground at some other station, or place. Place the alidade central on the table. Release the spindle clamp. Level the table carefully.

If the difference is small, it may be taken as levels are taken, for short distances.

Measure the height of the table from the ground and add this to the height of the level line of sight from the under side of the rule to get the height of the line of sight from the ground. Call this H. I. It is plus. Have a rod held at the place where the difference in elevation is to be taken. Sight by the level line of sight to the rod, and take a rod reading. Call this—S. It is minus. If compass sights are used, hold a pencil point at the forward mark, and be sure the table is well leveled. Subtract the rod reading

from H I (the height of the instrument) to get the difference in elevation. If the result is plus, the place where the rod was held is the higher; if minus, it is lower. If a telescope is used, it is set level by its striding level and the rod reading taken even if the table does not stand quite level. If better results are sought, have the table well leveled. If much nicety is required, lift the telescope from its transit axis bearings, turn it over, replace it with the transit axis reversed and the telescope the other side up, level it again, and take a second rod reading. Take the half sum of the two rod readings for the correct one. It will be easier to keep the telescope, its line of sight, and its striding level, in good adjustment where much of this is to be done, than it will to take double rod readings.

30. If the differences in elevation are too large to be reached in the way described, proceed as follows :

Get H. I. as before. Sight to a mark on the rod held up at the place, the same distance from the ground the line of sight is. With compass sights, hold a pencil point to the forward sight so it is in range from the peep sight to the mark on the rod. Take the reading of the scale on the forward compass sight at the pencil point. Multiply this by the distance in hundreds of feet to the rod for the difference in elevation. Record the scale reading $\pm$ with a note of the place where the rod was held, and do the multiplying at a convenient time. With a telescope, set the line of sight on a mark on the rod held at the place at the same height from the ground, the line of sight is. Read the vertical circle.

Record the reading $\pm$ with a note of the place the rod is held at. Set the telescope level, by means of its level. Read the vertical circle. Record the reading $\pm$ with the former reading. The difference between these two readings will be the angle of elevation, +, or depression, —, of a line joining the surface of the ground at the station where the table stands with the surface of the ground at the place where the rod is held. The distance between the two places may be taken from the plane table sheet, or measured. The difference in elevation equals this distance multiplied by the tangent of the angle. For greater refinements, the telescope may be turned over, and the observations repeated, taking the half sum of the two resulting angles for use. If the angle of elevation is not over 5° or 300', the difference in elevation may be computed by the following equation :

$$\text{Diff. in El.} = d \left\{ \frac{3 A - \frac{1}{10} A + \frac{1}{60} A - \frac{1}{3000} A}{100000} + .0000002 d \right\}$$

d = distance in feet. A = the angle in minutes. If A is an angle of elevation, the result will be plus, if an angle of depression, the result will be minus. The last term covers the correction for curvature and refraction and is always plus, as shown. The terms in the numerator give the $\tan.A$ at 5° , correct to 6 places. For $A < 5^\circ$ $\tan.A$ will be somewhat large, but only .00000043 for $A = 0^\circ 01'$. This equation can be used within the limits named, in place of tables.

31. When a stadia is used, the telescope must have cross wires in it to give stadia readings, and a stadia made to fit the cross wires and telescope. With this outfit, take and record the height of the

transit axis of the telescope from the ground at the instrument station. Hold up the stadia at the place whose distance and elevation is sought. Set the middle horizontal cross wire on a reading of the stadia, equal to the height of the transit axis from the ground. Read the vertical circle. Record the reading, $\pm$. Read the stadia at both the other horizontal cross wires. Record these readings. Set the telescope level, by means of its level. Read the vertical circle. Record this reading, $\pm$, with the former reading. For greater refinements, the telescope may be turned over, and the observations duplicated, taking the half sum of all readings for their final values, for use, with a note of the place the stadia was held at. The stadia notes may be reduced by any suitable method amongst those in use. For the determination of the constants relating to the particular telescope in use the methods given in Searle's Field Engineering 223d section, are good. The stadia may be used to determine contours, also, by the methods designated in such books as Johnson's Surveying, for such work.

32. Running a Straight Line.—If the line is already platted, set up the plane table at a station on the line, and orient it. The alidade being at the center of the sheet, mark its position on the paper by drawing fine lines at the ends of the work edge of the rule, and at the ends of the rule, so that the slightest movement of the rule on the sheet can be readily detected. Be particular to see that the levels read level. The line may then be run, as with a transit, reversing the plane table on its spindle as a transit is reversed, leaving the alidade undisturbed on

the sheet. Extreme care is required to keep from moving the alidade on the sheet.

In case the line is not platted and it is to be prolonged, set the line of sight on a mark, at a station of the line, in the direction from the plane table, opposite to that in which the line is to go ; using the hands to move the alidade over the sheet ; not disturbing the board, as it is oriented ; and keeping the edge of the rule at the center of the sheet. Reverse the telescope on its axis and locate a line staff in apparent line at the place where the next station is needed. Reverse the telescope on its axis, and see if the line of sight strikes the back sight mark. If it does not, repeat the pointings, correcting the leveling, or setting of the plane table till it will. Do not disturb the orientation of the table if the setting, or leveling, requires correction, or if it is disturbed, orient the table again. Having located the staff in apparent line, drive a stout stake, called a plug, in its place. While the plug is being driven, try the back sight again, see that the table is level, and be ready to give line for a point on the plug. Set the staff in line, on the plug, with the same tests by back sighting, as before. Mark the point, thus found on the plug, by a temporary mark, such as may be made by sticking the point of the line staff into the top of the plug a little. Release the spindle clamp. Reverse the plane table on its spindle. Level it again if needed. Set the line of sight on the back sight mark by means of the spindle clamp and slow motion screw, the alidade not being moved on the sheet. The table will no longer be oriented, being reversed, and may not be precisely in a reversed

position, that is, not just 180° from its first position, unless all parts of the alidade are in adjustment. Reverse the telescope on its axis and locate a second temporary mark on top of the plug, with the same tests, by back sighting as before. Drive a nail equidistant from the two temporary marks to mark the station on the line.

Set up a picket a little behind the plane table, and on line for a mark to back sight to from the forward station. A picket is a stick 3 or 4 feet long, about an inch or so thick, having a foot or so of its top straight and blazed off white, with its bottom end sharpened for driving into the ground. The picket is set so as to stand firm, with its white top end plumb and in line. If close to the table, it may be lined by looking back over the telescope tube, or, if the telescope is inverting, by looking through it from the object end. If a little distance away, the picket may be lined by sighting through the telescope in the ordinary manner.

Move the plane table to the forward station. Set it up and orient it. Use the station where it stood for a back sight, and continue the line as before.

Some telescopes do not reverse on their axes. They may be made in such cases to be lifted readily from the wyes or standards. With such a telescope the above directions need modification. Open the wye clips so the telescope can be lifted out before beginning to make the pointings. To reverse the telescope, lift it from the wyes; turn it over, end for end; and replace it with each end of its axis in the same wye it was in before. Otherwise than this, the pointings are made the same as with a telescope

that reverses on its axis. The chances of disturbing the alidade on the sheet are greater with this form of mounting, and corresponding care and pains are required.

If the telescope does not reverse, and does not lift out of the wyres, run the line by foresights.

To run a line by foresights, set up the plane table at a station of the line and orient it. Mark a station in the direction in which the line is to go to sight to, to get the line called a foresight. Set the line of sight on the foresight mark by moving the alidade over the sheet with the hands; not disturbing the board, as it is oriented; and keeping the edge of the rule at the center of the sheet. Mark the position of the rule on the sheet. Locate a point on a plug beyond the foresight, and where it can be seen from the foresight station. See if the line of sight still strikes the foresight. If not, repeat these operations till it will. Release the spindle clamp. Reverse the plane table on its spindle. Reverse the alidade on the sheet by the marks showing where the rule first rested. Level the plane table again if needed. Set the line of sight on the foresight by means of the spindle clamp and slow motion screw. The plane table is no longer oriented. Locate a second point on the plug beside the first, with the same tests. Drive a nail equidistant from the two marks on the plug to mark the station on the line.

Move the plane table to the foresight station. Set it up and orient it. Use the new station for a foresight, and continue the line as before.

When the line is not platted, or it is not necessary to orient the plane table to do other work, the

line may be prolonged by placing the alidade to the center of the sheet without orienting the table, and the first pointing made with the spindle clamp and slow motion screw.

The plat of the line as prolonged is found on the sheet by carefully continuing the piece that is there, platting the new stations located, and testing their position on the sheet by shots at well determined points, previously platted.

33. Intersecting Two Straight Lines.—

Extend the lines on the ground and set two plugs, with nails to mark one of the lines, the plugs standing one on each side of the other line, as nearly as can be judged. Stretch a string between the nails. Set a third plug under the string and on the other line. Drive a nail in this plug where the other line crosses the string. This nail will mark the intersection of the lines.

The two first plugs may, by miss-judgment, be on the same side of the second line. In that case extend the string to cross the second line and tie it to a stake. Or the first line may be marked by another plug which shall stand on the other side of the second line.

Sometimes the three plug method is inconvenient because the ground is so rough. Then set two plugs on each line so as to straddle the other ; draw two strings ; and set a nail in a fifth plug to mark the intersection.

Sometimes the last plug comes considerably below the string, or strings,—too far below for good sighting. In such a case hold a plumb line so as to look past it, and the string being used to line by.

Make the plumb line cover the string and the sight will be in a vertical plane with the string. A weight tied on a string will do. Steady the hand holding the plumb line on a staff if needed.

Sometimes strings cannot be stretched between the line plugs. Set up the plane table over the nail in one of the plugs ; set the line of sight on the nail in the other and do the sighting with the line of sight of the alidade. This takes more time. This plan may be used in case the intersection plug comes in a hole.

It may be sufficient for the purposes of the work to plat the lines on the paper and produce them there till they meet.

34. Measuring the Angle Between the Two Lines. — Intersect the lines. Measure the smaller angle between them.

Set up the plane table at the intersection of the lines. Measure off on the sides of the smaller angle between the lines from their intersection two hundred feet or more on each. Make the measurement carefully, and set a nail in a plug on each line to mark the ends of the measurements, using the alidade to line the marks with. Measure the distance between the two nails as precisely as practicable. Divide this distance in feet by twice the number of feet measurement off on the two lines from their intersection. The quotient will be the sine of one-half the angle between the lines. Look up the corresponding angle in the table of natural sines and multiply it by two to get the angle between the lines.

The same thing may be done with a scale on the drawing, using the plat of the lines thereon. If five

units of some convenient scale are used in laying off the distances on the two sides of the angle, one-tenth of the distance between the ends of the distances measured in the same unit will be the sine of half the angle sought.

One of the lines may need to be prolonged past their intersection to get the smaller angle. On the ground this will be done with the plane table as in running a straight line. On the drawing, do it with the rule.

The measurements made on the ground may be used at once with the scale and dividers to lay the angle down on the drawing without finding the value of the angle.

The process applies to the angle between two lines of a survey, or to the deflection angle from one to the next, since these angles are supplements of each other.

35. Laying out a Given Angle.—Plat the angle on the sheet of paper with its vertex at the center of the sheet. Draw the lines which form the sides of the angle out sufficiently to fit the rule of the alidade to, or mark pieces of them so the outer end of the rule can be fitted to them, if it is not desirable to draw the whole line. Or a separate extra piece of paper may be fastened on the board for this work. If the extra paper is used fasten it on first, find and mark the center of the sheet on it, and plat the lines from that. Set up the plane table at the plug or station, that is to be the vertex of the angle. Orient the table by one of the platted lines. Set the alidade to the other line. Range out this line by the

line of sight of the alidade, and mark it with plugs and nails on the ground.

If the given angle is much over 90° it will be better to plat its supplement on the plane table sheet, and produce one side of the plotted angle to get a plat of the given angle. This refers to the ordinary case in the field where there is no protractor. If a protractor is used, the angle can be laid down on the sheet at once with that. Without a protractor use the table of natural tangents or natural sines.

To plat an angle with natural tangents measure off from the vertex of the angle on the given or assumed side ten parts as large as can be conveniently used, as 10 or 20 inches. Here draw a perpendicular to the given side in the direction the angle is to lie. Take from the table the natural tangent of the angle. Move its decimal point one place to the right. Measure off on the perpendicular from the given side the resulting number of the same parts, ten of which were used in locating the perpendicular. Draw a line from the end of this measurement on the perpendicular to the vertex of the angle for the other side of the angle.

To plat an angle with natural sines take out the natural sine of half the angle and multiply this sine by two. With a radius of ten parts draw the arc of a circle with the vertex as a center and cutting the given side. With a radius of a number of the same parts equal to twice the sine of half the given angle with its decimal point moved one place to the right, and the intersection of the arc and the given side as a center, draw an arc cutting the first arc. Draw the

other side of the required angle from its vertex to the intersection of the two arcs.

36. Running a Traverse.— Run and plat the successive lines of the survey in the manner previously described for the various items of elementary work, or determine the vertices of the angles of the lines of the survey by any of the methods given. The result will be a plat of a continuous survey which is often called a traverse. Strictly speaking the plane table does not run a traverse in the sense of that term in transit work, but produces a plat of the lines traversed or surveyed. If computations are to be based on a plane table plat, the lengths of the sides should be measured on the ground with a steel tape and the plat checked by these measurements. The plat should also be to a large scale.

37. Obstacles on Straight Lines.— Obstacles are not frequently met with on ordinary plane table surveys. The lines of the survey are chosen so as to avoid them. It is, however, quite possible that they may be met with. If the scale of the plat on the board is so small that the object to be passed would appear insignificant, or the lines used to pass it too short for setting the alidade to, use an extra piece of paper, and plat the work to a sufficiently large scale while passing the object. This will permit the work to be checked, as well as to be done with sufficient precision.

38. Passing an Object on a Straight Line by Deflections. Fig. 5.— Fasten an extra piece of paper over the middle of the sheet. Find and mark the center of the sheet on the extra piece of paper. Set up the table and orient it at some point of A B,

the spindle clamp. Re-orient the table by the first line drawn from *m* towards C when at B, so as to orient the table with respect to A B. Set the alidade on C D and draw a line from *m* towards D. Move the table to D. Set it up. Orient it by the last line drawn.

Check.— Locate E, supposed to be in A B, produced. Place the alidade on the line first drawn from *m* towards C when at B. Release the spindle clamp. Turn the table round its spindle axis and set the line of sight on E by means of the spindle clamp and slow motion screw, leaving the alidade undisturbed on the sheet. See if the line drawn from *m* towards A when at B now points to C. If it does not, review the work and correct the errors.

If it is considered to be sufficiently accurate, the point C may be determined by resection from A B, and B C found from the plat. Good practice would make use of C in determining other points and objects required by the survey. In such a case B C and C D would be platted on the sheet with other stations. The distance B D may be found by platting B C and C D to a large scale from the center of the sheet on the extra sheet of paper and measuring the distance B D between their ends to the same scale. Or measure the angle B C D on the ground with the steel tape or on the plat with the scale (34) and find $B D = 2 B C \sin \frac{1}{2} B C D$.

For a check upon such work run past the object more than once, locating C in a different place, or prolong B C, and set another point on line beyond D. Run past on opposite sides where practicable. Set up the table at any one of the points beyond the ob-

ject. Orient it by the line to the station where the table stands. Locate E as before. See if the other points beyond the object are in the line to E. Apply the check above given at any of the points beyond the object and see if it fits.

39. Passing an Object on a Straight Line by Traversing. Fig.

6.—Run a traverse past the object, platting the lines of the traverse. The stations on the traverse may be determined by measurement, resection, or any of the usual methods. Extend the plat of the original line on the sheet to the forward part of the plat of the traverse. Draw a line on the plat from the last station of the traverse so as to intersect the straight line produced past the object, and in a position to be conveniently run out on the ground to reach the original line at a point beyond the object. Measure the length of this line on the sheet with the scale. Having set up the plane table at the last station of the traverse on the ground and oriented it, run out the above described line, measure out its length and locate a station beyond the object on the original line produced. Continue the line by means of the plat of it on the sheet.

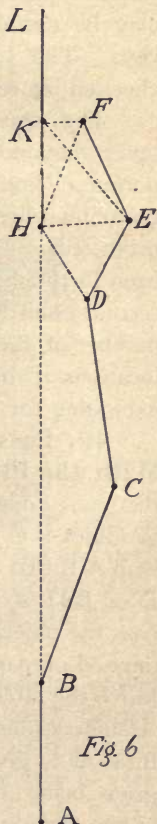


Fig 6

The above method is comparatively rough, but may be used in some cases. It is without a check. To improve the results, the traverse may be platted

on an extra sheet to a large scale, and the closing distance more carefully measured. More than one traverse may be carried past the object and the results compared. All the stations on all the traverses may be useful in extending or perfecting the survey. The points beyond the object may be checked by resection on other platted stations.

The traverse may be carried a sufficient distance beyond the object, as to D, E, and F, to permit of lines being drawn from E, and F, to H, the point where the closing line D H intersects A B, produced past the object. Locate H by intersections from D and E, and check it by resection on F. A second point K may be located by similar means. A number of these stations may be used to check the locations of one another, as well as form the basis for extending the survey.

40. Passing an Object on a Straight Line With the Plane Table Alone. Fig. 7:—Set up the plane table at B. Orient it by B A. Run out two lines B C and B D, making such equal angles with A B that they will pass the object. Set a station D on B D, so that D C perpendicular to A B will pass the object. Set plugs as near C as can be estimated preparatory to intersecting D C with B C. Move the table to D. Set it up. Orient it by D B. Assume a point *d* for the plat of D, on the plat of B, so as to give a good length to the lines of the diagram being developed on the sheet to set the rule of the alidade by. From *d* lay out a line on the sheet to represent the plat of D C, perpendicular to *a b*. Run this line out on the ground and intersect it with B C at C. Continue the line on the plat and find *c*.

Start the lines $D E$ and $D F$ for locating E and F at convenient angles from D B , and draw $d e$ and $d f$ on the plat to intersect $a b$ produced. Set plugs on $D E$ and $D F$, as near E and F as can be estimated preparatory to intersecting these lines with $C E$ and $C F$. Lay out $c e$ and $c f$ from c on the plat, making $B C E = B D E$ and $B C F = B D F$. Move the plane table to C . Set it up at C . Orient it by $C B$. Test its position by $C D$. Run out $C E$ and $C F$. Intersect them with $D E$ and $D F$, locating E and

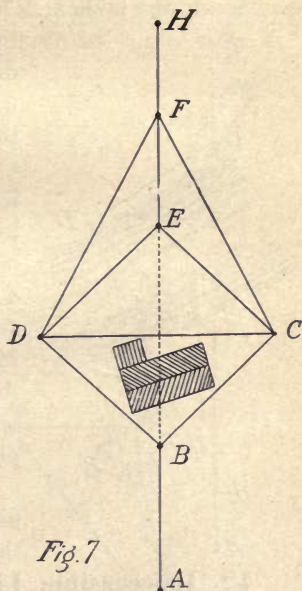


Fig. 7

F . Move the plane table and set it up at E or F , as may be most desirable. Orient it by the line to C . Test its position by $F E$ and the line to D . Continue the line to H , or any point beyond, using $F E$ or $A B$, as they should be the same.

This work may require an extra sheet of paper, but the practitioner will readily decide such matters for himself. C , D , E , and F , may be used as regular stations on the survey. The object may be plated as this work proceeds.

41. Passing an Object on a Straight Line by Resection. **Fig. 8.**—Locate E in $A B$ produced beyond the object. Choose D as any con-

plane table at I. Measure the angle $D I B = \triangle (34)$. Choose a suitable curve. The curve may be designated by its degree, like a railroad curve when the station chords, as $P_1 P_2, P_2 P_3$, etc., are 100 feet. When the station chords are not 100 feet, the curve may be named by using the station chord for the numerator of a fraction and the angle the station chord covers at the center of the curve, D , as the denominator, thus

$$\frac{20'}{10^\circ}$$

which signifies that a chord of 20 feet covers an angle at the center of the curve of 10° . This device may be called the "Name" of the curve. It corresponds

to the conception used in the term "Degree" used in railroad curves, which means the angle at the center covered by a station chord of 100 feet, or the numerator of the above fraction becomes 100. If the curve is designated by its degree, take its radius R , with $\log. R$, from a curve table. If the curve is "named," as above, compute

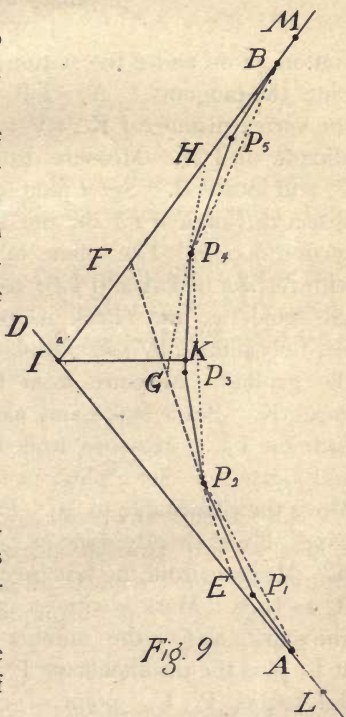


Fig. 9

$$R = \frac{\frac{1}{2} c}{\sin \frac{1}{2} d}, \text{ where } c = \text{the}$$

station chord and d the station angle it covers. Compute the tangents $I A = I B = T = R \tan \frac{1}{2} \Delta$, and the vertex distance $I K = V = T \tan \frac{1}{4} \Delta$. Set the alidade on $I M$. Measure from I towards M , $I B = T$, and locate B . Set a plug or stake and nail at B . Bisect the angle $a i b$ on the sheet, defining the direction of $i k$. The plane table should be oriented with respect to $I A$ and $I B$, using $i a$ or $i b$ to orient the table by, and check its position by the other. Set the alidade by $i k$. Range out the line $I K$ on the ground. Measure from I to K , $I K = V$, and locate K . Set a stake and nail at K . Set the alidade on $I L$. Measure from I towards L , $I A = T$, and locate A . Set a plug, or stake, and nail at A . Move the plane table to A . Put on an extra sheet of paper, if not already done at I . Set up the table at A . Measure from the last preceding station, as L , to A , as $L A$. Mark a witness stake for A , bearing the line mark, as Q ; the number of the regular station at L , plus the distance from L to A , as $147 + 62.37$; the letters $P. C.$, point of curve; the degree or name of the curve as 4° or

$$\frac{20'}{20^\circ}$$

the direction of the curve, as $L.$ for left, or $R.$ for right; and the angle $D I B = \Delta$, as $70^\circ 34' 30''$,

to read from the top of the stake downwards, — as

$$\begin{array}{r} Q \\ 147 + 62.37 \\ P. C. \\ 20' \\ \hline 20^\circ \\ C. R. \end{array}$$

C. R. for $70^\circ 34' 30''$. Drive this stake about a foot to the right of A, with its station number facing L.

Subtract the distance L A from the regular station distance, $P_1 P_2$ to get the first short chord, as $A P_1 = c_1$. Find one-half the angle this chord covers at the center of the curve, by

$$\sin \frac{1}{2} d_1 = \frac{\frac{1}{2} c_1}{R}$$

Subtract $\frac{1}{2} d_1$ from $\frac{1}{4} \Delta$. Divide the result by $\frac{1}{2} d$. The remainder found by this division will be $\frac{1}{2} d_2$, one-half the central angle, covered by the short chord $P_2 K = c_2$. Compute c_2 by

$$c_2 = 2 R \sin \frac{1}{2} d_2.$$

Subtract $\frac{1}{2} d_1$ from $\frac{1}{2} \Delta$. Divide the result by $\frac{1}{2} d$. The remainder found by this division will be $\frac{1}{2} d_3$, one-half the central angle covered by the short closing chord $P_3 B = c_3$. Compute c_3 by

$$c_3 = 2 R \sin \frac{1}{2} d_3.$$

Plat the angle $I A P_1 = \frac{1}{2} d_1$ with its vertex at the center of the sheet and with long sides for set-

ting the alidade by in running the curve. On the same side of this angle, supposing the observer to be at its vertex, that the curve is to run. plat $\frac{1}{2} d$, one-half the regular station angle. Number these lines 0, 1, 2, in the order they come in, laying down the angles platted. Still on the same side of the last angle platted, or continuing from line 2, plat $\frac{1}{2} d_2$ and number this line 3. From line 2 also plat $\frac{1}{2} d_3$ in the same direction and number this final line 4.

Set the alidade on 0. Set the line of sight on A I by means of the spindle clamp and slow motion screw. Set the alidade on 1. Take a distance on the chain, or tape, equal to $c_1 = A P_1$. Hold one end of this distance at A. Swing the other end of this distance on the tape into line at P_1 . Drive a stake at P_1 , marked for the number of that station, with the number facing A. Test this stake for line and distance, and when it is adjusted for both, drive a nail in it to mark the station P_1 . Set the alidade on 2. Hold one end of a distance on the tape, equal to the regular station chord, at P_1 . Swing the other end into line at P_1 . Set a stake at P_2 marked for that station, with the same tests that were used in setting P_1 . Set the alidade back on line 0. See if the line of sight still ranges the tangent A I. If not, review the work and correct the errors. Set the alidade on I. By means of the spindle clamp and slow motion screw set the line of sight on P_2 . Set the alidade on 2. Measure a regular station chord from P_2 and locate P_3 as P_2 was located. Set the alidade again on 1, and see if the line of sight strikes P_2 . If not, review the work from P_2 , and correct the errors. The alidade being set on 1, set the line of sight on

P_3 and continue the curve as before, making the various checks and tests to insure trustworthy work. So continue the work till the station next preceding K, the middle of the curve, is reached. This is P_3 in Fig. 9. After P_3 is set, and before shifting the table on its spindle preparatory to locating the next regular station, set the alidade on line 3. See if the line of sight strikes K. Measure the distance from P_3 to K. See if this equals c_2 . If either of these checks fail, review the work and correct the errors. Continue the curve from P_3 , not from K, till the station, as P_5 , next preceding the P. T. at B is reached. After P_5 is set and checked, set the alidade on line 4. See if the line of sight strikes the P. T. at B. Measure from P_5 to B. See if this distance is c_3 . If either of these checks fail, review the work and correct the errors. Mark a witness stake for the P. T. with the line mark; the station number of P_5 plus the distance P_5 to B; P. T.; the name of the curve; L or R; and the value of Δ . Drive this stake about a foot to the right of B, with the number facing P_5 . Subtract c_3 from the regular station distance to get the distance from B to M, the next regular station beyond B.

With the plane table oriented so the line 4 is directed to B, set the alidade on A I, and draw a line from m by the edge of the rule. Move the table to B. Set it up over B. Set the alidade on $m i$, the last line drawn. By means of the spindle clamp and slow motion screw, set the line of sight on A. Set the alidade on line 4. See if the line of sight ranges on the tangent B I. If not, review the work and correct the errors.

Range out the tangent I B. Measure $c-c_3$ from B to M, and locate the first regular station on the tangent beyond B, at M. Continue the tangent as a straight line (32).

In case the whole curve cannot be seen from A, run as far as practicable, as to P_2 in Fig. 9. After checking the location of the last station, set the alidade on line 1, and make the line of sight strike the last station by means of the spindle clamp and slow motion screw, just as if preparing to locate the next regular station. Set the alidade on A I. Draw $m i$ from m towards I by the edge of the rule. Move the plane table to P_2 . Set it up over P_2 . Turn the table so the same side of the sheet is forward the way the curve is going, that was forward when at A. Set the alidade on $i m$, the last line drawn, to look back to A. By means of the spindle clamp and slow motion screw set the line of sight on A. Set the alidade on line 2. Locate the next regular station in the usual manner, measuring a station chord from P_2 . Check its location by a back sight on A. Continue the curve as before directed for the table standing at A; also check on K as before directed.

Should it be necessary to move up again, let P_4 Fig. 9 be the station to be used as the next instrument station. Set the alidade on $i m$ again. By means of the spindle clamp and slow motion screw, set the line of sight again on A. Set the alidade on line 1. Make or find a mark in apparent line on the tangent E F. Call this mark F. Release the spindle clamp and set the line of sight on P_4 by means of the spindle clamp and slow motion screw, the alidade being still set on line 1. Set the alidade on P_2

F. Draw a line $m f$ by the edge of the rule. Move the plane table and set it up over P_4 . Turn the same part of the sheet to be forward as before. Set the alidade on $f m$ to look back to P_2 . Set the line of sight on P_2 by means of the spindle clamp and slow motion screw. Continue the curve as before.

Having moved up any number of times on a curve, let P_4 be the instrument station from which B can be seen and the curve closed. Before beginning work from P_4 after the table is oriented, set the alidade on line 1 and make or find a mark in apparent line on the tangent G H. Call this point H. Having closed the curve on B by line 4, leave the table with 4 pointing to B, and set the alidade on P_4 H. Draw $m h$ by the edge of the rule. Move the table to B. Set it up over B and orient it by $h m$, and a back sight on P_4 . Set the alidade on line 4. See if the line of sight ranges the closing tangent B I. If not, review the work and correct the errors.

To lay out a tangent at any station as P_4 and set up the plane table there, orient it preparatory to continuing the curve. Set the alidade on line 1, or whatever line was pointing to the instrument station from the previous instrument station when a pointing was made on the tangent there, preparatory to moving up. The line of sight then ranges on the tangent.

Obstructions to running the curve that cannot be removed may often be passed by a long chord. Compute the distance from the station where the plane table stands to the station beyond the obstruction which can be seen, by

$$C_1 = 2 R \sin \frac{1}{2} D_1,$$

where C_1 is the required distance, or long chord, and D_1 is the central angle covered by C_1 , found by the number of station chords on the curve between the two ends of C_1 . Run the curve as far as practicable towards the obstruction. Having checked the location of the last station, and without shifting the plane table, plat from line 2 an angle equal to one-half the central angle included between the last station located and the station at the far end of C_1 . Call the line thus laid down 5. Set the alidade on 2. See that the table is level and the line of sight strikes the last station located. If need be, level the table and set the line of sight on the last station located by the spindle clamp and slow motion screw. Set the alidade on 5. Run this line a distance C_1 from the station where the table stands and locate a station beyond the obstruction. Mark the tangent at the instrument station, as directed in the last paragraph. Orient the table so that 5 will point to the station located beyond the obstruction. Set the alidade on the tangent and draw a line by the edge of the rule from the center of the sheet. Move the table to the station located beyond the obstruction. Set it up there. Turn the table so the same side is forward as before. Set the alidade on the last line drawn, to look back at the station the table was moved from. Set the line of sight on that station by means of the spindle clamp and slow motion screw. Set the alidade on 5. Mark, or find a point in apparent line for a mark on the tangent at the new station. Set the alidade on 1. Set the line of sight on the tangent by the spindle clamp and slow motion screw. Set the alidade on 2. Measure from the in-



strument station a station chord, and locate the next regular station on the curve. Continue the curve as before.

To run the curve backwards to the obstruction, set the alidade on 2, instead of 1. Set the line of sight on the tangent by the spindle clamp and slow motion screw. Set the alidade on 1, so as to look back on the curve. Measure from the instrument station a station chord and locate the next regular station backwards on the curve. Continue the curve backward the same as forward, except that lines 1 and 2 exchange places in the order of their being used.

Where a plus station occurs, one-half the partial angle covered by the chord to it may be laid off on either side of one-half the regular angle, $1^m 2$, as may be required, as was done for starting the curve.

Wishing to know the plus station that would come on a designated line running from the instrument station, measure the angle (34) between it and a line to the last station located, or between it and the tangent at the instrument station. Call this angle $\frac{1}{4} d_4$.

Find
$$n = \frac{\frac{1}{2} d_4}{\frac{1}{2} d}$$

Reduce the decimal part of n to feet, or the units the station distance is measured in. Add the resulting number and plus to the number, and plus (if any), of the station where the plane table stands to get the number and plus of the station at the end of the line if $\frac{1}{2} d_4$ was measured from the tangent at the instrument station, or the last station located, if reckoning from there.

Lay the angles out on the sheet with great care. Be especially careful in setting the alidade to the lines on the sheet.

44. Laying Out Parabolic Curves. Fig.10.

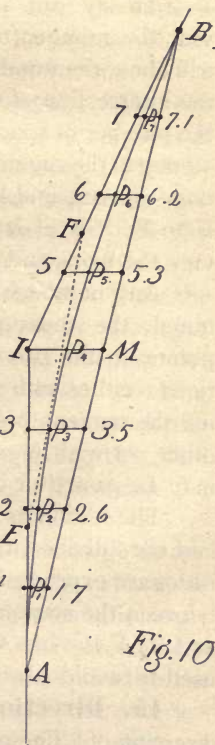
— These curves may be used where the tangents I A and I B are equal or unequal. The curve cuts the equally spaced breadths 1-1 2-2 etc., drawn parallel to the line I M, joining I with M, the middle point of A B, so as to make the following proportions. The distances 3-P₃; 5-P₅; etc., from the tangents I A and I B, and P₂-2; P₆-6; etc., from the chord A B are equal, if equally removed from I M. P₄ is in the middle of I M. 1-P₁; 2-P₂; 3-P₃; etc., are in the ratios of the squares of the natural numbers. P₁-1; P₂-2; P₃-3, etc., are in the ratios of the products of the natural numbers written from A to M, the one at M repeated, and continued back to A, as in the figure. This may be represented as follows :

o	o	A	A	o 8	o
1	1	1-P ₁	P ₁ -1	1 7	7
2	4	2-P ₂	P ₂ -2	2 6	12
3	9	3-P ₃	P ₃ -3	3 5	15
4	16	4-P ₄	P ₄ -M	4 4	16

Make an even number of divisions between A and I M.

Intersect the tangents A I and B I at I (33). Survey and plat these tangents. Set up the plane table at I. Locate the tangent points A and B at equal or unequal distances from I, as may be desired. It may be well to vary the positions of A or B slightly in order to make the spacings on the tangents, 1-3; 3-2; or 1-5; 5-6; etc., of a convenient length to lay

out. Lay out and locate 1, 2, 3, etc., on A I; and 5, 6, 7, etc., on I B, so as to divide each tangent into the same even number of equal parts. Move the plane table to A. Set it up at A and orient it by A I. Set the alidade on A B. Measure A B and plat it. See if it checks on *b*. If not, review the work and correct the errors. Locate M, the middle point of A B. Locate points 1; 2; etc., on A B, so as to divide A B into the number of equal parts in both tangents A I and I B. Measure I M on the ground and on the plat. See that they agree. Divide $\frac{1}{2}$ I M by the square of the number of divisions in the tangent A I, to get the unit measure for the work. Multiply this unit by the ratio numbers formed as above noted to get the measurements for locating points on the curve. Figure out both sets. Add them in succession for the various points P_1 ; P_2 ; etc. See if the results are in proportion to the natural numbers 1, 2, 3, etc. If not, review the figures and correct the errors. Stretch a cord, or tape, from 1 to 1. Locate P_1 on this line by the measurements for P_1 . Stretch a cord, or the tape, between 2 and 2. Locate P_2 on this line by the measurements for P_2 . So continue for each of the several



stations. Plat them on the sheet in the same manner. Measure from A to P_1 ; P_1 to P_2 ; P_2 to P_3 ; etc., around the curve. Record these measurements.

To lay out a tangent at any point, as P_3 . Divide the number of the point by 2. The quotient will show the number of spaces on A I, from A to E, the intersection of the required tangent with A I ; and the number of spaces on I B, from I to F the intersection of the required tangent with I B. Measure off these spaces, and locate E and F. Run a line from E to F. See if it passes through P_3 . If not, review the work and correct the errors.

Any number of tangents may be laid out as above noted, the measurements computed from them to points on the curve ; and these used in locating stations ; either with respect to A B, or the chord joining the tangent points of these tangents with each other, or with A or B. By this means obstructions may be passed or difficulties overcome.

The station as P_3 , at which a tangent as E F is laid out, divides that tangent into two parts whose ratios are expressed by the number of station distances between the station and A and B. E P_3 is $\frac{3}{8}$ ths and P_3 F is $\frac{5}{8}$ ths of E F. This principle may be used to avoid obstructions.

45. Direction of a Line. Fig. 11.— The direction of a line may be found by observing stars at their elongations. The stars near the pole are the most useful for this purpose. Their names and relative positions can be readily learned from a star map or a cheap planisphere. This will enable one to find the stars required for observation, or to tell the stars

that may be observed at any time. The apparent daily motions of the stars are in arcs of circles. When a star is at that part of its daily motion path, where it appears to move vertically, or follow the range of a plumb line, it is at its elongation. At the eastern elongation it is going upwards, at the western downwards. Western elongations are more convenient for observation with ordinary instruments. The observation is an easy one to make, as the star moves in a nearly vertical direction for some time. The observation consists in watching the star near its elongation, and keeping the range of a line to it. Finally get the direction of a line to the star when at its elongation. This is done by following the star with the vertical cross wire in a telescope, or by moving a compass sight on a level board, even keeping the star behind a suspended plumb line, when watching it through the compass sights,—or by any similar device. For further information regarding this kind of work consult an article on the “Direction of a Line,” in the *TECHNIC* for 1892.

Examine the plane table and find how large an angle of elevation can be observed with the rule standing on the board when sighting. Unless this angle considerably exceeds the latitude of the place of observation, a diagonal eyepiece will be required to the telescope. If compass sights are used the observation will need to be made on an entirely different plan.

To illuminate the cross-wires, tie a piece of unglazed white paper (common newspaper) over the objective by a string around the telescope tube back of the lens, with a hole in the paper centrally over

the objective. This hole may be from $\frac{1}{4}$ " to $\frac{1}{2}$ " broad. Light shining upon the outside of this paper will make the cross-wires visible. A lantern with a lens throwing light in one direction is best. A common lantern may be made use of by nearly surrounding it with something to shut off the light. The light must not shine in the observer's face. It must therefore shine obliquely from the side upon the paper over the objective. The light may be toned to any faintness within the telescope by withdrawing the lantern, or changing the obliquity of the beam of light.

Choose some point of the line whose direction is sought, or reference line, from which a clear view of the stars to be observed may be obtained for an instrument point. Fasten a lantern at some other point of the reference line to sight to. A common lantern about a mile away will do very well. If necessary to have it nearer a fainter light may be made by covering part of the lantern globe. This light should be faint enough to look about like a faint star, so that no change of focus of the objective will be required.

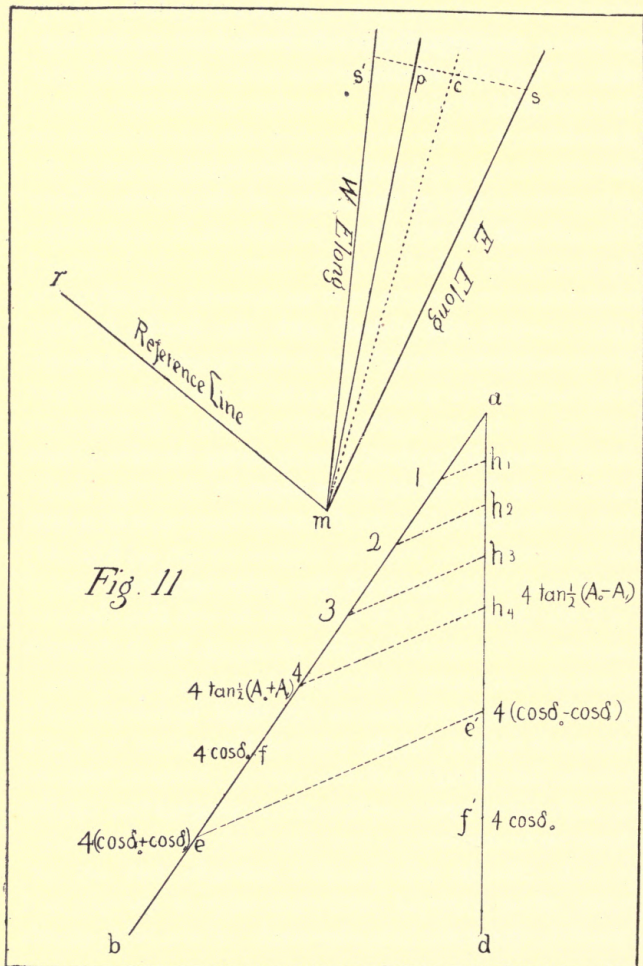
In good season for beginning the observations, set up the plane table over the instrument point of the reference line, with a sheet of paper on for this work. Set a needle at the center of the sheet as a guide for the edge of the rule. Turn the board so there will be room on the paper, on the side towards the stars to be observed, and a good place for the plat of the reference line. Clamp the spindle. Set the alidade on the reference line, sighting to the distant lantern, the cross-wires being illuminated. Use the

hands in setting the alidade, and keep the edge of the rule to the needle at the center of the sheet. Draw a line from the center of the sheet by the edge of the rule,— *m r*, Fig. 11. Place the alidade to look at a star, the edge of the rule being kept to the needle. Direct the telescope to a star. Bring the star into the field of view of the telescope by the hands. Illuminate the cross-wires. Set the vertical wire on the star, using the hands and keeping the edge of the rule to the needle at the center of the sheet. Keep this wire on the star very carefully as it approaches its elongation, which may be known by the increased time taken by the star to cross the wire. Follow the star, moving the alidade with the hands, keeping the vertical wire exactly on it till it appears to pass directly along this wire. Presently it will leave this wire and go to the same side it came from. Follow it no longer than till it passes directly along the wire. Draw a line from the center of the sheet by the edge of the rule. Mark this line for the star observed with a note of its elongation, east or west,— as *m, s*, Fig. 11. Set the alidade again on the reference line. See if *m r* fits the rule. If it does not fit well this observation must be rejected. The nicety of the fit depends upon the character of the work.

To save confusion on the sheet in case the rule does not fit *m r*, set the edge of the rule to *m r*, and set the line of sight on the distant lantern, with the spindle slow motion screw as a preparation for the next observation.

In case the rule fits well enough, but not exactly, draw a second line by the edge of the rule and mark both for the star observed. If the table stands

still till time for the next observation, mark the second line for next star.



Observe a second star as the first was observed. Draw a line marked for it as $m s'$. Take a pointing again on the reference line as before. Mark the reference line drawn on the board if it differs from the last,—otherwise note the fact that the lines checked.

If there are two lines $m r$ drawn on the sheet for the observation of a star, draw a third line bisecting the angle between them for the line to be used in making the reductions which follow, unless there is good reason to take one of the original lines drawn,—if there is, use that line.

Observe three or more stars in this way, noting the line for each, and the elongation of each.

The lines to the stars are to be taken in pairs and the position of the meridian line found graphically. There may be as many results found as there are pairs that can be formed from the number of stars observed. Three stars will give 3 pairs and 3 results. Four stars will give 6 pairs and 6 results. And so on.

Let Fig. 11 represent the lines needed in finding the position, $m p$, of the meridian.

Take from the Nautical Almanac the apparent declinations of the stars for the date of the observation.

If A_0 = the azimuth of the star s and δ_0 = its apparent declination, and A_1 = the azimuth of the star s' and δ_1 = its apparent declination, the following equations may be written.

$$\text{Tan } \frac{1}{2}(A_0 + A_1) = \frac{\tan \frac{1}{2}(A_0 - A_1) (\cos \delta_0 + \cos \delta_1)}{\cos \delta_0 - \cos \delta_1}$$

$$\text{Tan } \frac{1}{2}(A_0 - A_1) = \frac{\tan \frac{1}{2}(A_0 + A_1) (\cos \delta_0 - \cos \delta_1)}{\cos \delta_0 + \cos \delta_1}$$

These equations may be solved graphically, being simple proportions.

Bisect the angle $s m s'$ by a line $m c$. Lay off $m c$ equal to ten parts of some scale, as large as may be. Draw $s s'$ perpendicular to $m c$ at c . Draw two indefinite lines $a b$ and $a d$, making any convenient angle with each other. Lay off $a f$ and $a f' =$ natural cosine of δ_0 , or any multiple of $\cos \delta_0$ (in this case 4 was used) to the same scale $m c$ was measured by. Lay off $f e$ equal to the same multiple of $\cos \delta_1$, to the same scale, and $f e' = f e$. Lay off $a i = s c = s' c$. Also $1, 2 = 2, 3 = 3, 4 = s c$, if desired. Join e and e' . Draw parallels to $e e'$ through 1, 2, 3, and 4, intersecting $a d$ in h_1, h_2, h_3 , and h_4 ; $a h_1$ should equal h_1, h_2 ; $h_2 h_3$; and $h_3 h_4$. From c on $s s'$, lay off $c p = a h_1$, towards the line which marks the star having the greater declination, because the star having the greater declination will have the smaller azimuth from the north at its elongation. Draw $m p$. $p m r$ is the angle between the reference line and the meridian

By taking the stars observed in pairs, a separate result may be obtained for each pair, and the final location of $m p$ made more trustworthy. If the lines become too numerous and the drawing too complicated, separate drawings may be made for each pair by pricking the line $m r$ and the lines for a pair of stars through onto a separate sheet, and doing the drawing on that sheet. After the angle $p m r$ is found it can be compared with the value on the original sheet.

There are four cases of this graphical solution. The reference line $m r$ may be between $m s$ and $m s'$,

or not, as in Fig. 11. The stars may be at the same elongation or at different elongations, as in Fig. 11. In case the stars are at the same elongation the distance corresponding to $c p$ will represent $\tan \frac{1}{2} (A_0 + A_1)$ and must be laid off from c towards the place of the meridian $m p$, that is, to the left of c if the stars are both at the eastern elongation, or to the right of c if at the western elongation, when the direction $m p$ is to the N. The circumstances of each case will dispose of all ambiguity.

Lay off the denominator of the fraction in the second number of either equation and the distance corresponding to $s c$ on the same line. Lay off on the other line that part of the numerator depending for its value upon δ_0 and δ_1 . Join the points located by functions of δ_0 and δ_1 , and draw a parallel or parallels to this line as required. A multiple of the cosines is taken in order to bring c and c' a good distance apart. $s' c$ was laid off four times as a test of the precision of the drawing. The lines $a b$ and $a d$ should be open enough to give good intersections at h_1 , h_2 , etc., better than in Fig. 11.

The angle $p m r$ may be measured (34), and the work oriented with respect to the meridian. The meridian $m p$ may be laid out on the ground if desired.

The meridian may be laid out on the ground directly, without platting the lines on the sheet if desired. After observing a star at its elongation, point the telescope downwards and set a stake marked for the star with a point marked on it in line. Do the same for two or more stars, setting the stakes as far away as convenient, yet near enough for the points

on them to be well located. Reverse the telescope about its axis ; shift the rule to the other side of the needle at m ; and level the table anew after observing

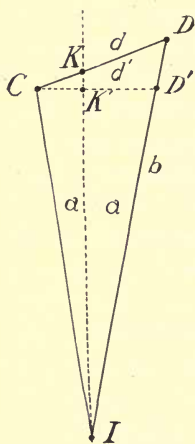


Fig. 12

and marking the line to each star. Make notes showing the position of the telescope when observing each star. In combining the observations in pairs, place together those for two stars for which the notes show the telescope to have been in two different positions. By so doing the imperfections of the instrument will do less harm.

If I in Fig. 12 shows the place of the plane table C and D, the stakes for two stars, one at its E. elongation and the other at its W. elongation, and I K the meridian, make the following measurements carefully,—as with a steel tape. $CD = d$; $IC = a$; and $ID = b$. Let $x = CK$, and $y = KD$, the segments of CD between the meridian and C and D.

$$x + y = d$$

$$x - y = d \frac{a \cos \delta_0 - b \cos \delta_1}{a \cos \delta_0 + b \cos \delta_1}$$

where δ_0 is the apparent declination of the star represented by C, and δ_1 the apparent declination of the star represented by D. Find x and y and locate K with the plane table and steel tape. As a check on the figuring use

$$\frac{x}{y} = \frac{a \cos \delta_0}{b \cos \delta_1}$$

when the stars are at the same elongation $d = x - y$ and

$$x + y = d \frac{a \cos \delta_0 + b \cos \delta_1}{a \cos \delta_0 - b \cos \delta_1}$$

In this case K will not come between C and D but to the right of D if the stars are in the W. elongation, or to the left of C if in the E. elongation. Should D' be set in line from I to D so that $ID' = IC = a$, the figuring would be simpler. Measure $CD' = d'$, and

$$x' - y' = -d' \tan \frac{1}{2} (\delta_0 + \delta_1) \tan \frac{1}{2} (\delta_1 - \delta_0).$$

For the stars at the same elongation $d' = x' - y'$ and

$$x' + y' = -d' \cot \frac{1}{2} (\delta_0 + \delta_1) \cot \frac{1}{2} (\delta_0 - \delta_1).$$

An inspection of this last equation shows that stars having nearly the same declination should not be used together, if observed at the same elongation.

Since $A_0 = C I K$ and $A_1 = D I K$, the azimuths of the stars at their elongations, $C I D = A_0 + A_1$. For the stars in the same elongation, $C I D = A_0 - A_1$. Measure $C I D$ with the plane table or compute its value from the steel tape measurements. Then

$$\tan \frac{1}{2} (A_0 - A_1) = -\tan \frac{1}{2} (A_0 + A_1) \tan \frac{1}{2} (\delta_0 + \delta_1) \tan \frac{1}{2} (\delta_0 - \delta_1)$$

$$\tan \frac{1}{2} (A_0 + A_1) = -\tan \frac{1}{2} (A_0 - A_1) \cot \frac{1}{2} (\delta_0 + \delta_1) \cot \frac{1}{2} (\delta_0 - \delta_1)$$

Observations on stars having nearly the same declination, made at the same elongation, should not be combined.

The latitude of the place ϕ may be computed as follows :

$$\cos \phi = \frac{\cos \delta_0}{\sin A_0} = \frac{\cos \delta_1}{\sin A_1}$$

Whence it appears that the direction of the meridian and the latitude of a place may be found

without reading angles. A_0 and A_1 may be found directly from the triangles C I K and D I K.

In case a plane table is used having compass sights on its alidade the direction of the meridian may be found as follows : Suspend a long plumb line from a fixed support so high that the stars to be observed will appear somewhat below the support. Use a large piece of stone or some bricks for the bob, and let it hang in a vessel of water to steady the line. Drive two stakes some distance S. of the plumb line, and nearly in an E. and W. line. Saw off their tops to the same elevation. Nail a smooth board on top of the stakes. The stakes should stand firm, at such a distance S. of the plumb line that with the eye a little above the board, the stars to be observed will appear below the support of the plumb line. The length of the board should be 6 or 8 ft. if about 20 ft. S. of plumb line. Level the board carefully, both ways. Remove one of the compass sights from the rule of the alidade. As a star approaches its elongation place the rule on the board with the compass sight to the south, the rule pointing to the plumb line. Looking through the compass sight keep the plumb line over the star by shifting the alidade with the hands on the board. Follow the star till it appears to pass directly along the plumb line, and leave it again on the same side it approached from. Illuminate the plumb line if need be by a light from behind the observer. Follow the star no longer than till it passes directly along the plumb line. Keep the rule pointing as nearly as may be to the plumb line all the time. Mark the place where the slit in the compass sight stands on the board and number the

mark. Record in the note-book the same number with the name of the star and a note of the elongation, E. or W. Observe 2 or more stars in this manner. Measure the exact distances of each of the marks on the board from the plumb line. Measure very fully the distances of each mark on the board from all the others. Record these measurements. Reduce the position of the meridian by calculations similar to those above given, remembering that the triangle C I D, Fig. 12, lies S. of I. The point K may then be marked on the board. The line from K on the board to the plumb line should be very carefully produced by repeated sightings. This may be done with a field glass, if one is to be had, by driving a nail at K in the board, standing back a sufficient distance, and using the field glass to see that the stake and nail beyond is set in line of K and the plumb line. Better prolong the line some distance S. of the board, and then N. of the plumb line, setting stakes and nails in both directions.

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